



# Analytical Rideshare Model by Considering Locations of Drivers and Passengers: Why Ridesharing Fell Flat in Local Japan

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by

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JAPAN

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# Analytical Rideshare Model by Considering Locations of Drivers and Passengers

- Why Ridesharing Fell Flat in Local Japan -

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## Abstract

Even sharing economy grows slowly in Japan, there is a high expectation for ridesharing in local areas[1]. Authors have been conducting ridesharing surveys centering around Hokkaido Teshio, Nakatonbetsu and Tsubetsu. While ridesharing has become an urgent need, nevertheless, the results were not efficient as expected in the demonstration experiments.

We consider that the main cause is that ridesharing supply falls short of demand because of the limited routes. Rideshare demonstration experiments in limited routes or areas are smaller than inhabitants' living areas. Therefore, users and drivers are difficult to match with each other.

The purpose of this paper is to prove that cooperation of municipalities is necessary for a more effective ridesharing system. Further more, we analyze the effects from geographical factors such as size and position on ridesharing match through the linear area model[2].

**Keywords:** Ridesharing; Depopulated municipalities; Demonstration Experiments

# 1 Introduction

As known that the population of Japan is on the decline. Particularly in Hokkaido, where the percentage of depopulated or partially depopulated municipalities comes to 83.2%, while the percentage of the whole Japan is 46.4%. These municipalities have low population densities and financial indexes, resulting in a lack of public transports. In addition, there are more elderly residents who are difficult to drive on themselves. We regard production-age population as driver population and make a comparison between 2007 and 2017 (see Appendix A for the index map). There is an 8% decline of the whole Hokkaido, and in Yubari and some other areas, over 30% drivers decreased in the past 10 years in particular. Due to issues as mentioned above, these municipalities are facing a serious problem that imperils their existence.

Sharing economy is considered as an effective way to remedy this situation. As the National Strategic Special Zone Council enacted a regulation for ridesharing in depopulated municipalities in May 2016, ridesharing demonstration experiments have been in progress in three areas by this stage. However, all of these experiments have a constraint that ridesharing trips only happen in limited routes or areas: Teshio has a system that trips should start in Teshio and end in Wakkanai. While in Nakatonbetsu, trips are limited in domestic area. Thirdly one, close to Kyoto, trips can only start in Kyotamba and end in Kyōtango. Based on traffic censuses and interviews on Teshio and Nakatonbetsu, we found that rideshare systems should have got an effective effort, but in demonstration experiments, they were used under one time a day.

It is necessary to study the reason why ridesharing demonstration experiments fell flat in Japan, therefore find a solution. Existing researches of rideshare are almost on cities and countries where successful systems have been established and great masses of trips are happening every day, like America and China[3] [4][5]. But in Japan, harder laws and regulations limit the development of rideshare[6]. Cho clarified that transfer can improve the result of rideshare[7]. However, there are few pieces of research about modeling real rideshare system. Osawa formulated a theoretical linear model of plural countries[2]. In this paper, we introduce this linear model to study rideshare systems. Presume ridesharing probability subjects to the cooperation and geographic factors. We divide the linear area into plural municipalities and calculate the ridesharing probability of each municipality. In section2, we divide rideshare trips to 3 level to analyze how the cooperation strength of municipalities impacts on the probability of rideshare. In section3, we discuss a two-municipality model with different sizes to study the effects of municipality size. In section4, we discuss the three-municipality model and  $n$ -municipality model with identical sizes to study the effects of municipality position and number.

## 2 Three Levels of Rideshare trip

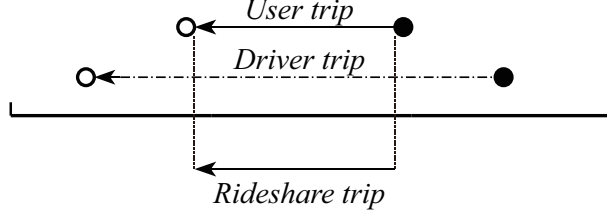


Figure 1: Linear area

In real north Hokkaido, there is always only one route between two municipalities. Prefectural road 106 crosses boundaries of plural municipalities, becoming the live line of inhabitants there. User and drive's trips are on a common road, which makes it possible to analyze the rideshare system on a linear area.

In our model, the linear area is divided into  $n$  municipalities,  $n \in N$ . Length of segments define municipality sizes; the sequence of segments define municipality positions. Denote the overall length of the whole model as  $L$ , the size of  $i$  municipality as  $l_i$ ,  $n \in N$ .

$$L = \sum_{i=1}^n l_i \quad (1)$$

Ridesharing can be matched successfully when driver's trip includes user's trip and both of them are in the same direction. As the Figure 1, rideshare trip is equal to the user's trip. Rideshare trips of one municipality can thus be regarded as trips when the users depart from this municipality. Denote ridesharing probability of the model as  $P$ , ridesharing probability of  $i$  municipality as  $P_i$ . Denote matching probabilities of users in  $i$  municipality as  $p_i$ , matching probabilities of drivers in  $i$  municipality as  $q_i$ .

$$P = \sum_{i=1}^n P_i = \sum_{i=1}^n p_i \quad (2)$$

And we assume that 4 points: origins and destinations of driver and user are uniformly and independently distributed in the linear area. Rideshare trips of  $i$  municipality, defined as the origins of users distributed in  $i$  municipality, are classified into three levels according to distribution of other points.

- *level  $\alpha$* : User's trip completes in  $i$  municipality, and the driver also departs from  $i$ .
- *level  $\beta$* : User's trip completes in  $i$  municipality, while the driver's trip is unlimited.
- *level  $\gamma$* : User's trip completes in  $i$  municipality or not, meanwhile the driver's trip is unlimited.

### 3 Two-Municipality Model

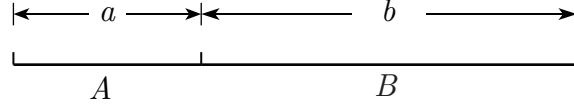


Figure 2: Two-municipality model

In this section, the linear area is divided into municipality  $A$  with a length  $l_A = a$  and municipality  $B$  with a length  $l_B = b$ , as shown in Figure 2,  $L = a + b$ .

When one point is uniformly and independently distributed in this model, the odds of being in segment  $A$  is  $a/L$ , while being in segment  $B$  is  $b/L$ . So distribution of one trip, with two points, can be shown in a  $OD$  graph (the vertical axis is the destination and the horizontal axis is the origin).

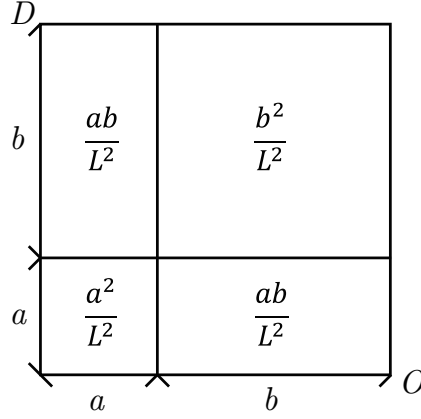


Figure 3:  $OD$ -graph of two-municipality model  $L = a + b$

Matching probability is different with positional relationship of the user and driver. For example, distribution density that 4 points are all distributed in segment  $A$  is  $a^4/L^4$ , matching probability under this pattern comes to  $2/4! = 1/12$ . While the user with a trip  $\overrightarrow{AB}$  can not match with the driver with a trip  $\overrightarrow{AA}$  or  $\overrightarrow{BB}$ . Next table shows matching probability under each distribution pattern.

Table 1: Patterns of two-municipality model

User \ Driver	$\overrightarrow{AA}$	$\overrightarrow{AB}$	$\overrightarrow{BA}$	$\overrightarrow{BB}$
$\overrightarrow{AA}$	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{1}{6}$	-
$\overrightarrow{AB}$	-	$\frac{1}{4}$	-	-
$\overrightarrow{BA}$	-	-	$\frac{1}{4}$	-
$\overrightarrow{BB}$	-	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{12}$

### 3.1 Ridesharing Probability in three level

The ridesharing probabilities of *level  $\alpha$* , *level  $\beta$*  and *level  $\gamma$*  over the linear area are denoted as  $P^\alpha$ ,  $P^\beta$  and  $P^\gamma$ , respectively. From our definition in section2,  $P^\alpha$  is when the user's trip begins and ends in a municipality, the driver's also begins in the same one, so:

$$P^\alpha = \frac{a^4}{12(a+b)^4} + \frac{a^3b}{6(a+b)^4} + \frac{b^4}{12(a+b)^4} + \frac{b^3a}{6(a+b)^4}.$$

Result of each level is as follows:

$$P^\alpha = \frac{a^4 + 2a^3b + 2ab^3 + b^4}{12(a+b)^4}, \quad (3)$$

$$P^\beta = \frac{a^4 + 4a^3b + 4ab^3 + b^4}{12(a+b)^4}, \quad (4)$$

$$P^\gamma = \frac{1}{12}. \quad (5)$$

Minimum value occurs when  $a = b$ , defined as two municipalities have the same size:

$$P^\alpha = \frac{1}{32} (\approx 0.031), \quad P^\beta = \frac{5}{96} (\approx 0.052).$$

Next is a graph showing ridesharing probability of  $a$ , the size of municipalityA. (the vertical axis is the ridesharing probability and the horizontal axis is the proportion of  $a$  in  $a + b$ ).

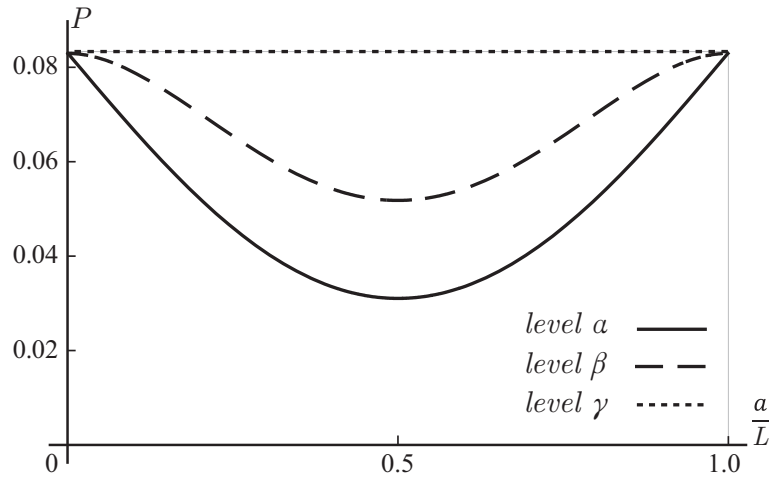


Figure 4: Ridesharing probability in each level

### 3.2 Matching Probability of users and drivers

From Table 1, we can also analyze matching probabilities of users and drivers. Denote matching probabilities of users and drivers departing from municipality  $A$  as  $p_A$  and  $q_A$ , matching probabilities of users and drivers departing from municipality  $B$  as  $p_B$  and  $q_B$ . From our definition in section 2,  $p$  and  $q$  can also be classified into 3 level. Follows are the results.

At the *level*  $\alpha$ , user's trip completes in one municipality, and the driver also departs from there.

$$p_A = q_A = \frac{a^4 + 2a^3b}{12(a+b)^4}, \quad (6)$$

$$p_B = q_B = \frac{2ab^3 + b^4}{12(a+b)^4}. \quad (7)$$

At the *level*  $\beta$ , user's trip completes in one municipality, while the driver's trip is unlimited.

$$p_A = \frac{a^4 + 4a^3b}{12(a+b)^4}, \quad q_A = \frac{a^4 + 2a^3b + 2ab^3}{12(a+b)^4}, \quad (8)$$

$$p_B = \frac{4ab^3 + b^4}{12(a+b)^4}, \quad q_B = \frac{2a^3b + 2ab^3 + b^4}{12(a+b)^4}. \quad (9)$$

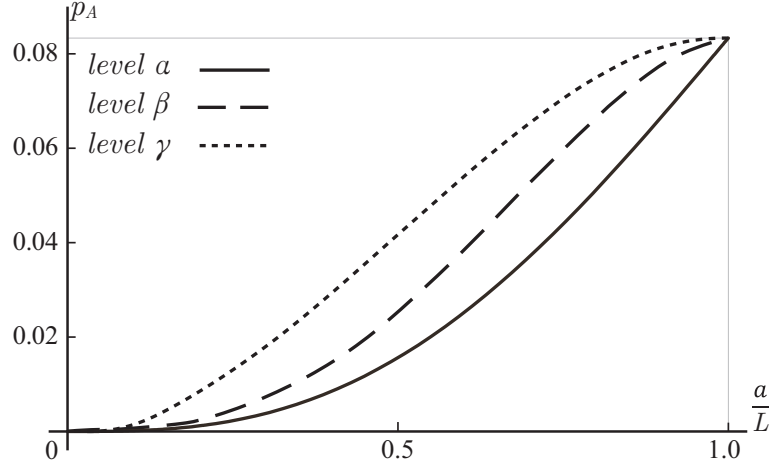
At the *level*  $\gamma$ , user's trip can end in other municipality or not, meanwhile the driver's trip is unlimited.

$$p_A = \frac{a^4 + 4a^3b + 3a^2b^2}{12(a+b)^4}, \quad q_A = \frac{a^4 + 2a^3b + 3a^2b^2 + 2ab^3}{12(a+b)^4}, \quad (10)$$

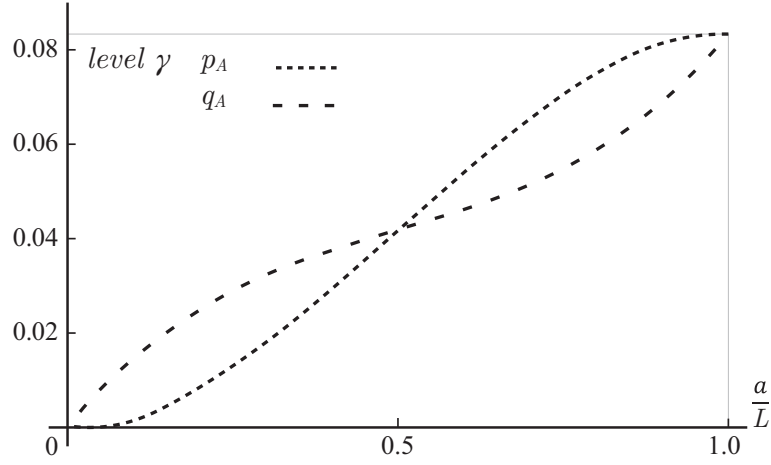
$$p_B = \frac{b^4 + 4ab^3 + 3a^2b^2}{12(a+b)^4}, \quad q_B = \frac{b^4 + 2ab^3 + 3a^2b^2 + 2a^3b}{12(a+b)^4}. \quad (11)$$

Figure 5(1) shows matching probabilities of users departing from  $A$  on each level. Due to formula(2), it also can be regarded as ridesharing probabilities function of municipality  $A$ . Figure 5(2) shows matching probabilities of users and drivers departing from  $A$  on *level*  $\gamma$  (the vertical axis is the proportion of  $a$  in  $a+b$  and the horizontal axis is the probability.)





(1) Matching probability of user at each level.



(2) Matching probability of user and driver at level  $\gamma$ .

Figure 5: Matching probability

### 3.3 Brief Summary

Three points can be suggested from above:

1. From formula(3)-(5), ridesharing probability of each level shows  $P^\alpha < P^\beta < P^\gamma$ , and  $P^\gamma$  is consistent with it of the overall area. We also find that matching probabilities of user show  $p^\alpha < p^\beta < p^\gamma$ , and for drivers,  $q^\alpha < q^\beta < q^\gamma$ . These results prove that strengthening the cooperation between municipalities can improve effectiveness of rideshare system.
2. From Figure 5(1), the functions show that larger municipalities can gain more benefits from rideshare system.
3. From Figure 5(2), when  $a \leq b$ , it shows  $p_A \leq q_A$  and  $p_B \geq q_B$ . This result shows that drivers in smaller municipalities and users in larger municipalities can gain more benefits from rideshare system.

## 4 $n$ -Municipality Model

In this section, we will begin with a three-municipality model( $n = 3$ ), and expand to  $n$ -municipality model next.

### 4.1 Three-Municipality Model

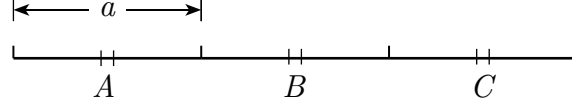


Figure 6: Three-municipality model

In this section, the linear area is divided into municipality  $A, B, C$  with an identical length  $l_A = a$  as shown in Figure 6. The overall length of model is  $L = 3a$ . Regard  $A, C$  as outer municipalities and  $B$  as inner municipality. Clearly,  $A$  and  $C$  have a symmetry property.

When one point is uniformly and independently distributed in this model, the odds of being in each segment is  $a/L = 1/3$ . So one trip defined by origin and destination point has an uniform distribution density as  $a^2/L^2$ , shown as its  $OD$ -graph in Figure 7. (the vertical axis is the destination and the horizontal axis is the origin).

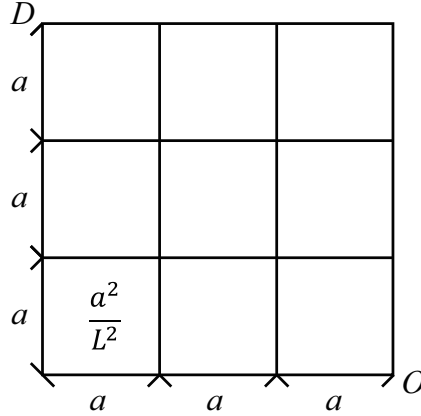


Figure 7:  $OD$ -graph of three-municipality model ( $L = 3a$ )

When a user matches with a driver, due to the identical sizes, every pattern has an uniform distribution density as  $a^4/L^4$ . However, matching probability is different with positional relationship of the user and driver. See Appendix B for further particulars of all patterns.

The ridesharing probabilities of *level*  $\alpha$ , *level*  $\beta$  and *level*  $\gamma$  over the linear area are denoted as  $P^\alpha$ ,  $P^\beta$  and  $P^\gamma$ .  $p_i$  and  $q_i$  are defined as matching probabilities of users and drivers departing from municipality  $i$ ,  $i \in \{A, B, C\}$ .

From formula(2) and symmetry property between  $A$  and  $C$ , ridesharing probability of the whole model comes to

$$P = p_A + p_B + p_C = 2p_A + p_B. \quad (12)$$

Ridesharing probability of each level is shown as follows.

$$P^\alpha = \frac{5a^4}{4L^4} = \frac{5}{324},$$

$$P^\beta = \frac{13a^4}{4L^4} = \frac{13}{324},$$

$$P^\gamma = \frac{27a^4}{4L^4} = \frac{1}{12}.$$

From our definition in section2,  $p$  and  $q$  of each municipality can also be classified into 3 level. Follows are the results.

At the *level*  $\alpha$ ,

$$p_A = q_A = p_B = q_B = p_C = q_C = \frac{5}{972}.$$

At the *level*  $\beta$ ,

$$p_A = p_C = \frac{1}{108}, \quad p_B = \frac{7}{324},$$

$$q_A = q_C = \frac{5}{324}, \quad q_B = \frac{1}{108}.$$

At the *level*  $\gamma$ ,

$$p_A = p_C = \frac{7}{324}, \quad p_B = \frac{13}{324},$$

$$q_A = q_C = \frac{11}{324}, \quad q_B = \frac{5}{108}.$$

From formula, we can see matching probabilities increase with level. While regarding  $A$ ,  $C$  as outer municipalities and  $B$  as inner municipality, we conclude that users in inner municipality and driver in outer municipality can have more chance to match successfully. In other words, gain more benefit in recent system.

## 4.2 $n$ -Municipality Model

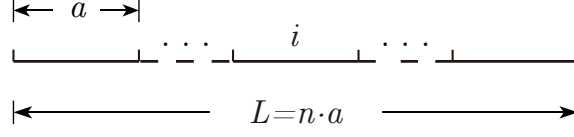


Figure 8:  $n$ -municipality model

After introduction of the three-municipality model, we expand into  $n$ -municipality model to analyze the effect from the number of cooperation municipalities on rideshare system. Similar to section 4.1, in  $n$ -municipality model, the line area is divided into  $n$  municipalities and each of them has an identical size  $l = a$  as shown in Figure 8, and the overall length of model is  $L = n \cdot a$ .  $i, j$  are two random segments in this model, defined as two municipalities on the linear area. Due to the identical sizes, each single trip has an uniform distribution density of

$$\rho = \frac{l^2}{L^2} = \frac{1}{n^2}. \quad (13)$$

From formula(2), we can analyze three levels of rideshare systems by matching probabilities of users from  $i$ . Assume that one user has a trip  $\vec{ij}$ , distribution density of the user is  $\frac{1}{n^2}$ . Figure 9 is the  $OD$ -graph of the driver who matching to this user, showing his distribution density. Distribution of the driver also determines matching probability. In table 2, we give the results under all patterns.

$j$		$D$		
		$\frac{(i-1)(n-j)}{n^2}$	$\frac{(n-j)}{n^2}$	$\frac{(n-i)(n-j)}{n^2}$
		$\frac{(i-1)}{n^2}$	$\frac{1}{n^2}$	$\frac{(n-i)}{n^2}$
		$\frac{(i-1)(j-1)}{n^2}$	$\frac{(j-1)}{n^2}$	$\frac{(n-i)(j-1)}{n^2}$
		$i$		
		$O$		

Figure 9:  $OD$ -graph of  $n$ -municipality model

Table 2: Patterns of  $n$ -municipality model

$j < i$				$j = i$				$j > i$			
D \ O	< $i$	$i$	> $i$	D \ O	< $i$	$i$	> $i$	D \ O	< $i$	$i$	> $i$
< $j$	-	$\frac{1}{2}$	1	< $j$	-	$\frac{1}{6}$	$\frac{1}{2}$	< $j$	-	-	-
$j$	-	$\frac{1}{4}$	$\frac{1}{2}$	$j$	$\frac{1}{6}$	$\frac{1}{12}$	$\frac{1}{6}$	$j$	$\frac{1}{2}$	$\frac{1}{4}$	-
> $j$	-	-	-	> $j$	$\frac{1}{2}$	$\frac{1}{6}$	-	> $j$	1	$\frac{1}{2}$	-

From the combination of Figure 9 and Table 2, we see at the *level*  $\alpha$ ,  $j = i$ , and origin of driver should be in  $i$  too, so,

$$P_i^\alpha = \frac{1}{n^4} \left( \frac{n-1}{6} + \frac{1}{12} \right) = \frac{1}{12n^4} (2n-1). \quad (14)$$

At the *level*  $\beta$ ,  $j = i$  too. Origin of driver is unlimited. From the addition of table(1),

$$\begin{aligned} P_i^\beta &= P_i^\alpha + \frac{1}{n^4} \left( \frac{n-1}{6} + (i-1)(n-i) \right) \\ &= \frac{1}{12n^4} (-12i^2 + 12(n+1)i - 8n - 3). \end{aligned} \quad (15)$$

At the *level*  $\gamma$ ,  $j$  is independent on  $i$ , so result comes from the addition of table(1)-(3),

$$\begin{aligned} P_i^\gamma &= P_i^\beta + \frac{1}{n^4} \left( (i+j)(n+1) - 2ij - n - \frac{1}{2} \right) \\ &= \frac{1}{12n^3} (-6i^2 + 6(n+1)i - 3n - 2). \end{aligned} \quad (16)$$

Ridesharing probability of each level can be calculate from the sum of  $P_i$ . Follows are the results.

$$P^\alpha = \sum_{i=1}^n P_i^\alpha = \frac{1}{12n^3} (2n-1). \quad (17)$$

$$P^\beta = \sum_{i=1}^n P_i^\beta = \frac{1}{12n^3} (2n^2 - 2n + 1). \quad (18)$$

$$P^\gamma = \sum_{i=1}^n P_i^\gamma = \frac{1}{12}. \quad (19)$$

Next is a graph showing ridesharing probabilities with the number of municipalities from 1 to 10. (the vertical axis is the probability and the horizontal axis is the number of municipalities,  $\{n \in N | 1 \leq n \leq 10\}$ ).

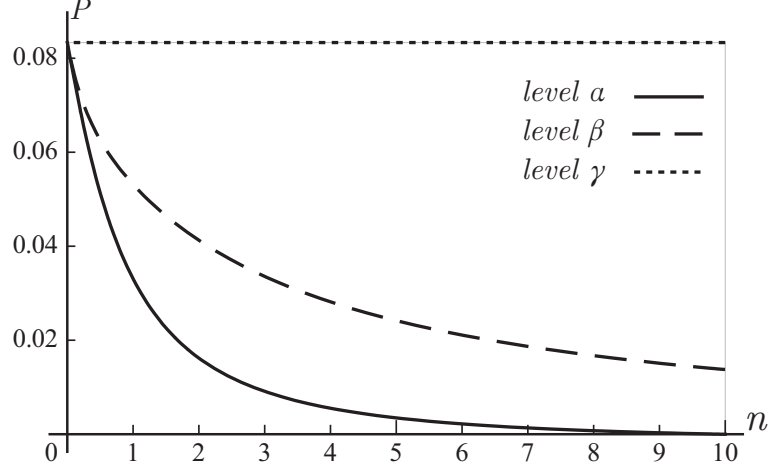


Figure 10: N-municipality model

For  $i$  municipality, matching probabilities of users is  $p_i$ , matching probabilities of drivers is  $q_i$ .  $p_i = P_i$ , and  $q_i$  of 3 levels can also be calculated from above.

At the *level*  $\alpha$ ,

$$p_i^\alpha = \frac{1}{12n^4}(2n - 1). \quad (20)$$

$$q_i^\alpha = \frac{1}{12n^4}(2n - 1). \quad (21)$$

At the *level*  $\beta$ ,

$$p_i^\beta = \frac{1}{12n^4}(-12i^2 + 12(n + 1)i - 8n - 3) \quad (22)$$

$$q_i^\beta = \frac{1}{12n^4}(6i^2 - 6(n + 1)i + 3n^2 + n + 3). \quad (23)$$

At the *level*  $\gamma$ ,

$$p_i^\gamma = \frac{1}{12n^3}(-6i^2 + 6(n + 1)i - 3n - 2). \quad (24)$$

$$q_i^\gamma = \frac{1}{12n^3}(6i^2 - 6(n + 1)i + 2n^2 + 3n + 2). \quad (25)$$

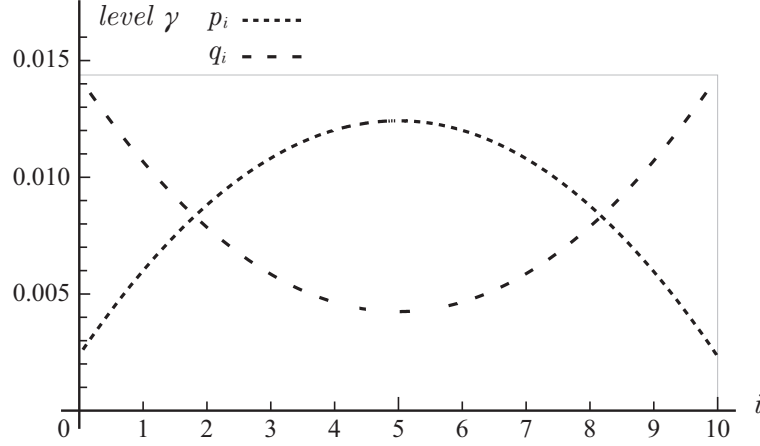


Figure 11: Matching probabilities of users and drivers  $n = 10$

### 4.3 Brief Summary

Two points can be suggested from above:

1. From Figure 10, the functions of different levels show that with the strengthening the cooperation, rideshare system can be more stable.
2. From Figure 11, users in inner municipalities and drivers in outer municipalities can gain more benefits from rideshare system.

## 5 Conclusion

To find the reason why rideshare demonstration experiments are undesirable in Japan, we analyze the ridesharing probabilities based on real rideshare systems in depopulated municipalities. Even if residents are not conscious of municipal boundaries, experiments are limited by geographic factors. From the discussion of two-municipality-model with different sizes and  $n$ -municipality-model with identical sizes. Rideshare demonstration experiments were conducted in small municipalities, however, we find that large municipalities can gain more benefits from rideshare systems. Furthermore, strengthening the cooperation between municipalities can improve effectiveness of rideshare. And also, increasing the number of covered municipalities can make rideshare system more stable. Besides, we analyze matching probability of users and drivers, and to find that matching probability of users is unbalanced with it of drivers. Specifically, drivers in smaller outer municipalities and users in larger inner municipalities can gain more benefits from rideshare system. Hence, expanding the scale is necessary for a sustainable rideshare system.

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## A Driver population index of Japan

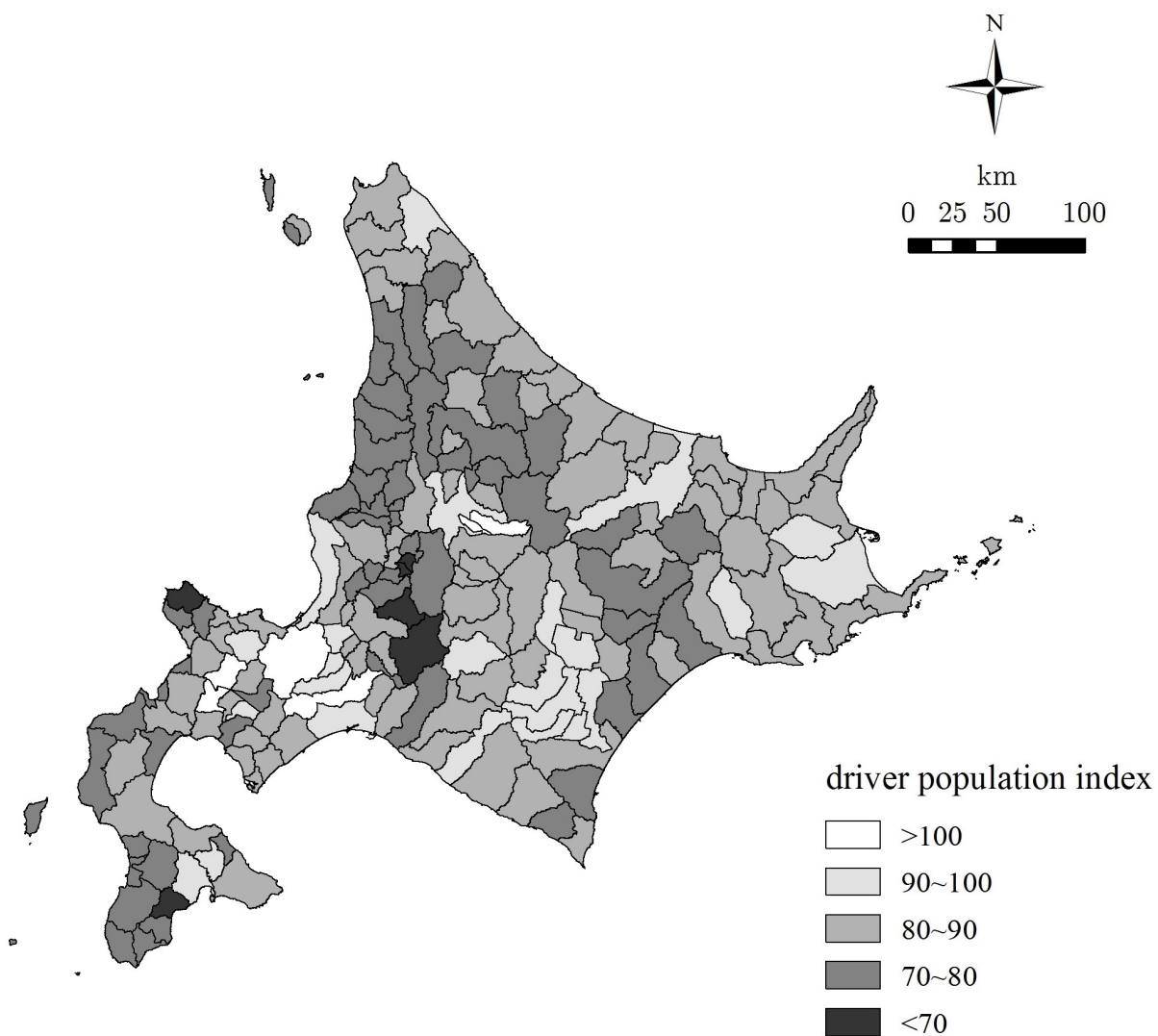


Figure 12: Driver population index (from 2007 to 2017, when 2007=100)

## B Patterns of three-municipality model

Table 3: Patterns of three-municipality model

User \ Driver	$\overrightarrow{AA}$	$\overrightarrow{AB}$	$\overrightarrow{AC}$	$\overrightarrow{BA}$	$\overrightarrow{BB}$	$\overrightarrow{BC}$	$\overrightarrow{CA}$	$\overrightarrow{CB}$	$\overrightarrow{CC}$
$\overrightarrow{AA}$	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	-	-	$\frac{1}{6}$	-	-
$\overrightarrow{AB}$	-	$\frac{1}{4}$	$\frac{1}{2}$	-	-	-	-	-	-
$\overrightarrow{AC}$	-	-	$\frac{1}{4}$	-	-	-	-	-	-
$\overrightarrow{BA}$	-	-	-	$\frac{1}{4}$	-	-	$\frac{1}{2}$	-	-
$\overrightarrow{BB}$	-	$\frac{1}{6}$	$\frac{1}{2}$	$\frac{1}{6}$	$\frac{1}{12}$	$\frac{1}{6}$	$\frac{1}{2}$	$\frac{1}{6}$	-
$\overrightarrow{BC}$	-	-	$\frac{1}{2}$	-	-	$\frac{1}{4}$	-	-	-
$\overrightarrow{CA}$	-	-	-	-	-	-	$\frac{1}{4}$	-	-
$\overrightarrow{CB}$	-	-	-	-	-	-	$\frac{1}{2}$	$\frac{1}{4}$	-
$\overrightarrow{CC}$	-	-	$\frac{1}{6}$	-	-	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{6}$	$\frac{1}{12}$